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MEMORANDUM

TO: Whom it may concern

FROM: Tim Rehder, Rocky Flats Team Leader

SUBJECT: Radiation Risk and Radiation Dose, How Do They Relate?

During the long public debate that has surrounded the radiological soil action levels (RSALs) for Rocky Flats, questions have routinely come up on the issues of radiation dose and radiation; questions like what is a safe dose, what risk level does that dose equate to? Unfortunately, the answers to these questions are not always straight forward. The EPA Guidance Document “Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination,” August 1997, says that a 15 mRem dose/yr is approximately equal to a risk of 3×10^{-4}. This over simplification has lead to much of the confusion stakeholders, public officials and regulators have experienced on this issue. In fact, the level of risk associated with a given dose depends on a number of factors such as: 1) the method used to convert dose to risk, 2) the radionuclide of interest and 3) the route(s) of exposure.

Let's talk first about the methods used to calculate the risk posed by exposure to radioactive materials. There are basically two methods for doing so; 1) calculating the Effective Dose Equivalent (EDE) and then converting that dose into a risk number, or 2) calculating a risk using cancer Slope Factors.

The Dose Conversion Method

The oversight panel is familiar with the concept of dose assessment. It is an assessment performed to answer the question "how much dose will an individual receive when exposed to a specified amount of radioactive materials?" When we talk about dose we are generally referring to the effective dose equivalent (EDE), which is a unit of measure developed by the International Commission on Radiologic Protection (ICRP) to normalize radiation doses by considering the adverse effects on a total body basis for the purpose of regulation of occupational exposure. In theory, if the EDE is calculated correctly, the risk associated with receiving, for example, a 1,000 mRem dose from Plutonium is equal to the risk associated with receiving 1,000 mRem from Radium, Cesium or any other radionuclide. EDE is derived by multiplying a dose conversion factor (DCF) for a given radionuclide by the unit intake of exposure to that radionuclide (i.e. ingestion, inhalation or external exposure). The following factors are considered in the development of dose conversion factors for the various radionuclides:

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- type of radiation
- relative strength (or energy) of the radiation
- different radionuclides will target different organs or tissues
- different organs or tissues will exhibit different cancer induction rates.

A simple example that illustrates how dose is calculated is a man who breathes 20 m^3 per day and lives year round at a location where the concentration in air of Plutonium is 0.1pCi/m^3. In this scenario the man is neither drinking contaminated water, eating contaminated foodstuffs, nor ingesting contaminated dirt. Assuming all the airborne Plutonium is respirable, and for this example using a DCF for inhalation of Pu of 0.308 mRem/pCi, the equation would look like:

example 1
(365 days/year)(20 m^3/day)(0.1 pCi/m^3)(0.308 mRem/pCi)(30years) = **6750 mRem**

Since different radionuclides have different DCFs, if we changed the radionuclide in the equation above, the resulting dose would be different. Similarly, different routes of exposure have different DCFs. If we considered ingestion rather than inhalation in the equation above, the resulting dose would be different.

Most health physicists don't calculate the risk that is associated with a given dose. They simply compare the dose to accepted national standards : e.g. 100 mRem/yr for public exposure or 5,000 mRem/yr for occupational exposure. However, risks can be calculated using a two-step method. The first step being the dose calculation as demonstrated in example 1 above. The next step is to convert the dose to a risk value using a **probability coefficient**. ICRP has developed probability coefficients that allow dose to be expressed in terms of risk. The 1990 Recommendations of the ICRP says the probability coefficient from fatal cancers, non-fatal cancers and severe hereditary effects is 7.3×10^{-2}/sievert (1 sievert = 100,000 mRem). This risk coefficient is based on low LET (Gamma) radiation and considers all cancers. Using that coefficient, the next step in calculating risk is:

example 1 -step 2

(6750 mRem)(7.3×10^{-2}/sievert) = 5×10^{-3}.

Slope Factor Method

A slope factor is similar to a dose conversion factor, but instead of assigning a unit dose for every unit of exposure (i.e. mRem/pCi) a unit of **RISK** is assigned for every unit of exposure (i.e. probability of adverse effect/pCi). Using an inhalation slope factor for Plutonium of 3.33×10^{-8}/pCi we can go back to the above example and calculate a risk:

example 2

$(365 \text{ days/year})(20 \text{ m}^3\text{/day})(0.1 \text{ pCi/m}^3)(3.33 \times 10^{-8}\text{/pCi})(30 \text{ years}) = 7.2 \times 10^{-4}$

Note that this result is lower than the risk calculated in example 1 using the Dose Conversion Method. EPA believes that for internal exposures to alpha and beta emitters, the Slope Factor Method produces a more reliable estimate of risk.

EPA has calculated slope factors for most of the radionuclides and just as different radionuclides have different DCFs, different radionuclides generally have different slope factors. The slope factors also vary depending on route of exposure. Therefore, risk associated with inhaling 1,000 pCi of Uranium is different from that of inhaling 1,000 pCi of Cesium. Also the risk associated with inhaling 1,000 pCi of Radium is different from that of ingesting 1,000 pCi of Radium via drinking water.

Summary

There are two methods for calculating the risk associated with radiation exposure:

> 1) The Dose Conversion Method where a dose is calculated by multiplying a dose conversion factor (expressed in terms of unit dose/unit intake) for a given radionuclide by the total intake of exposure to that radionuclide (i.e. ingestion, inhalation or external exposure). The dose is multiplied by a probability coefficient to arrive at a risk value.
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> 2) The Slope Factor Method where risk is calculated directly by assigning a unit of **RISK** for every unit of exposure (i.e. probability of adverse effect/pCi), and multiplying that by the total exposure. This method is basically the same method that EPA uses to calculate the risks associated with non-radioactive carcinogens.

EPA believes that the Dose Conversion Method is fine for calculating the risks of exposure to low LET radiation (i.e. gamma radiation), but does not work well for internal exposure to alpha and beta emitting radionuclides. In the case of internal exposure, the Dose Conversion Method tends to overestimate the risk as seen in the two example calculations above.

The risk associated with 15 mRem/year, as stated in recent EPA guidance documents is based on the ICRP risk value of .073/Sv for external low LET radiation. All external low LET radiation can use this value. (A new EPA calculated value is closer to .08/Sv) The calculation for deriving the 3×10^{-4} number is as follows:

> $(15 \text{ mRem/yr})(30 \text{ yrs})(7.3 \times 10^{-2}\text{/sievert}) = 3 \times 10^{-4}$

Again, EPA believes that this estimate of the risk associated with a 15 mRem/yr dose is only reliable for external low LET radiation (gamma radiation).

NOTE ON COMPARING CALCULATED RISK NUMBERS TO THE ACCEPTABLE RISK RANGE

When making this comparison, EPA generally rounds the number up or down. For example, EPA has gone on record saying 3×10^{-4} (3 in 10,000) is essentially equal to 1×10^{-4} (1 in 10,000). In another case, EPA made the call that 5.7×10^{-4} is **not** equal to 10^{-4}.